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Permalloy Film Array Spin Dynamics and High Performance Integrated Microwave Devices

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5c. PROGRAM ELEMENT NUMBER
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6. AUTHORS
Pingshan Wang

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
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Clemson, SC 29634 -5702

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14. ABSTRACT
Major contributions of this project include (1) the highest permalloy (Py) array FMR frequency reported so far without DC magnetic bias field, and (2) an ultra-sensitive method for ferromagnetic material characterization.
Shape-induced high frequency properties of patterned submicron Py arrays are obtained. Py films are sputtered and patterned on gold (Au) transmission lines. Chromium (Cr) is used as adhesion layers for Au and Py deposition. Each Py bar in the arrays is 10 ?m long and 100 nm thick. The widths of the Py bars in two different arrays are 240 nm and 550 nm, respectively. Micromagnetic simulations indicate single domain magnetization distribution in these Py structures. The

15. SUBJECT TERMS
microwave devices, permalloy thin films, spin dynamics

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Pingshan Wang
U	U	U	SAR		19b. TELEPHONE NUMBER: 864-656-2117

Report Title

Permalloy Film Array Spin Dynamics and High Performance Integrated Microwave Devices

ABSTRACT

Major contributions of this project include (1) the highest permalloy (Py) array FMR frequency reported so far without DC magnetic bias field, and (2) an ultra-sensitive method for ferromagnetic material characterization.
Shape-induced high frequency properties of patterned submicron Py arrays are obtained. Py films are sputtered and patterned on gold (Au) transmission lines. Chromium (Cr) is used as adhesion layers for Au and Py deposition. Each Py bar in the arrays is 10 ?m long and 100 nm thick. The widths of the Py bars in two different arrays are 240 nm and 550 nm, respectively. Micromagnetic simulations indicate single domain magnetization distribution in these Py structures. The measured ferromagnetic resonance frequencies (FMR) without bias field are ~ 11.5 GHz and ~ 8 GHz, respectively.
A new high-frequency method is proposed and demonstrated to significantly reduce parasitic effects through an on-chip interference process. As a result, measurement sensitivity is dramatically improved in comparison with conventional on-chip transmission line FMR methods. On-chip 10-GHz structures were fabricated to experimentally demonstrate a 35-dB sensitivity improvement. To demonstrate the proposed algorithms, a total of 180 patterned micro-Py stripes are used. Reasonable FMR line width and complex permeability are obtained.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Pingshan Wang, Hanqiao Zhang, Ralu Divan, Axel Hoffmann, “Tailoring High-Frequency Properties of Permalloy Films via Submicron Patterning”, Accepted for publication in IEEE Transactions on Magnetics.

Number of Papers published in peer-reviewed journals: 1.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Song, Chunrong; Liu, Zuqin; Eres, Gyula; Geohegan, David B.; Wang, Pingshan; “A New Method for Microwave Characterization of Metallic Single-Walled Carbon Nanotubes,”
Nanotechnology, 2008. NANO '08. 8th IEEE Conference on
18-21 Aug. 2008 Page(s):228 – 229
Zhang, Hanqiao; Song, Chunrong; Divan, Ralu; Hoffmann, Axel; Wang, Pingshan; “High-Frequency Properties of Permalloy Nanowire Arrays for RF Devices,”
Nanotechnology, 2008. NANO '08. 8th IEEE Conference on
18-21 Aug. 2008 Page(s):621 – 624.

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts): 2

(d) Manuscripts

Hanqiao Zhang, Chunrong Song and Pingshan Wang, “A new method for high-frequency characterization of patterned ferromagnetic thin films,” submitted to Journal of Applied Physics.

Number of Manuscripts: 1.00

Number of Inventions:

Graduate Students

NAME	PERCENT_SUPPORTED
Hanqiao Zhang	1.00
FTE Equivalent:	**1.00**
Total Number:	**1**

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:.....	0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:.....	0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):	0.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:	0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense	0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:	0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME
Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

5 **High-Frequency Structures for Nanoelectronics and Molecular Electronics**

Patent Filed in US? (5d-1) Y

Patent Filed in Foreign Countries? (5d-2) N

Was the assignment forwarded to the contracting officer? (5e) N

Foreign Countries of application (5g-2):

5a: Chunrong Song

5f-1a: Clemson University

5f-c: 215 Riggs Hall

Clemson SC 29634

5a: Pingshan Wang

5f-1a: Clemson University

5f-c: 215 Riggs Hall

Clemson SC 29634

Permalloy Film Array Spin Dynamics and High Performance Integrated Microwave Devices

Project: 2005567

Final Report

Pingshan Wang

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Project results

1. Period of the project: (08/01/06-07/31/08)
2. Total amount of budget: $50,000/24 months
3. Main achievements
    a. Publications
        i. Pingshan Wang, Hanqiao Zhang, Ralu Divan, Axel Hoffmann**,** **"**Tailoring High-Frequency Properties of Permalloy Films via Submicron Patterning", Accepted for publication in *IEEE Transactions on Magnetics*.
        ii. Hanqiao Zhang, Chunrong Song and Pingshan Wang, "A new method for high-frequency characterization of patterned ferromagnetic thin films," submitted to *Journal of Applied Physics.*
        iii. Hanqiao Zhang, Chunrong Song and Pingshan Wang, "A new method for high-frequency characterization of patterned ferromagnetic thin films," (abstract) *accepted for presentation in 53rd Magnetism and Magnetic Material, 2008*.
        iv. Song, Chunrong; Liu, Zuqin; Eres, Gyula; Geohegan, David B.; Wang, Pingshan; **"**A New Method for Microwave Characterization of Metallic Single-Walled Carbon Nanotubes," Nanotechnology, 2008. NANO '08. 8th IEEE Conference on 18-21 Aug. 2008 Page(s):228 – 229
        v. Zhang, Hanqiao; Song, Chunrong; Divan, Ralu; Hoffmann, Axel; Wang, Pingshan; "High-Frequency Properties of Permalloy Nanowire Arrays for RF Devices," Nanotechnology, 2008. NANO '08. 8th IEEE Conference on 18-21 Aug. 2008 Page(s):621 – 624.
    b. Patent application:
        i. Pingshan Wang, Chunrong Song, "High-Frequency Structures for Nanoelectronics and Molecular Electronics", Application Serial No. or PCT Application No. 60/951,510, filing date 07/24/2007
4. Student supported: Hanqiao Zhang, Ph. D. student, began to work on the project since January, 2007.

Results not submitted for publication yet

1. FMR frequency dependence on transverse biasing field and DC current.

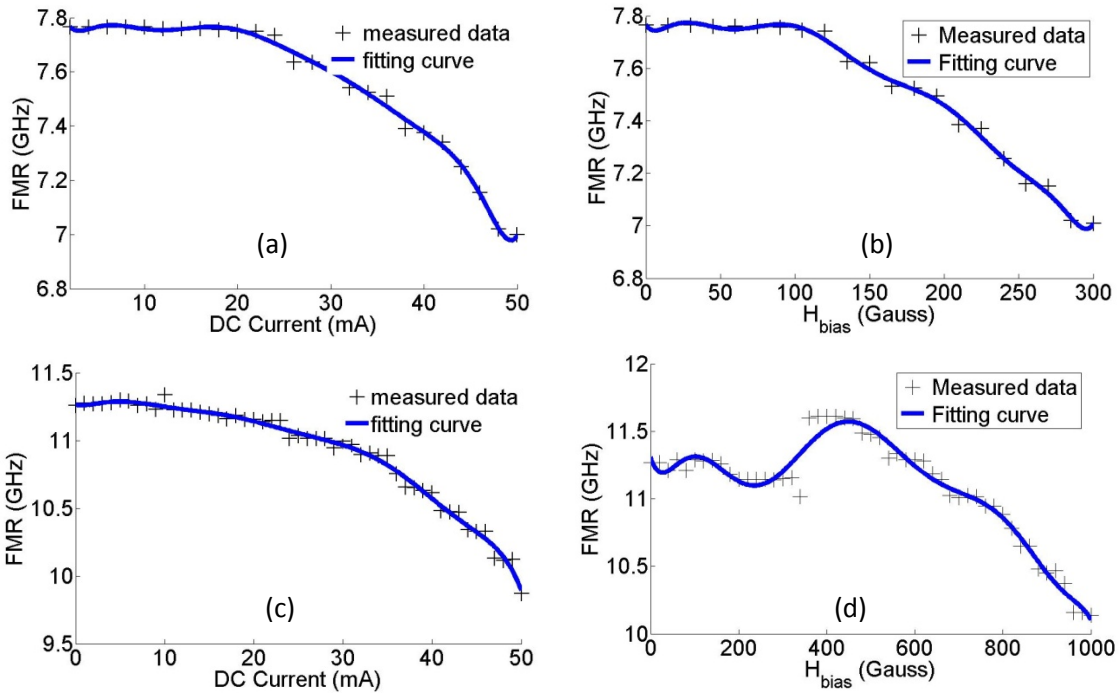

Fig. 1 FMR frequency dependence on DC current and external magnetic field. (a) and (b) are for 550 nm Py arrays. (c) and (d) are for 240 nm arrays. The reasons for the discrepancies between current excitation and field excitation are still under investigation.

2. High-frequency inductor

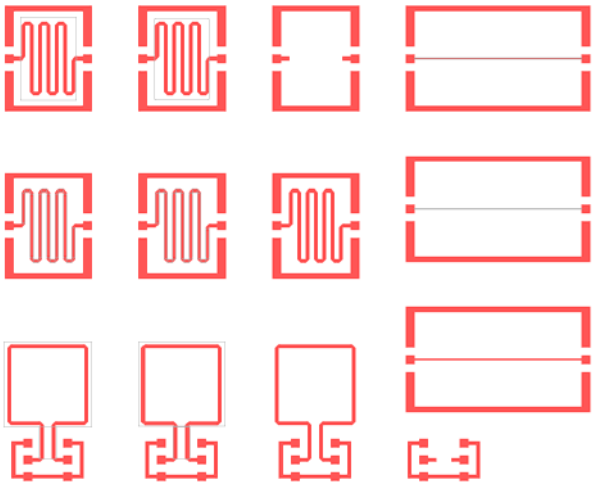

Fig. 2 Py loaded inductors (still under fabrication)